Open-Charm results on gluon polarization from COMPASS

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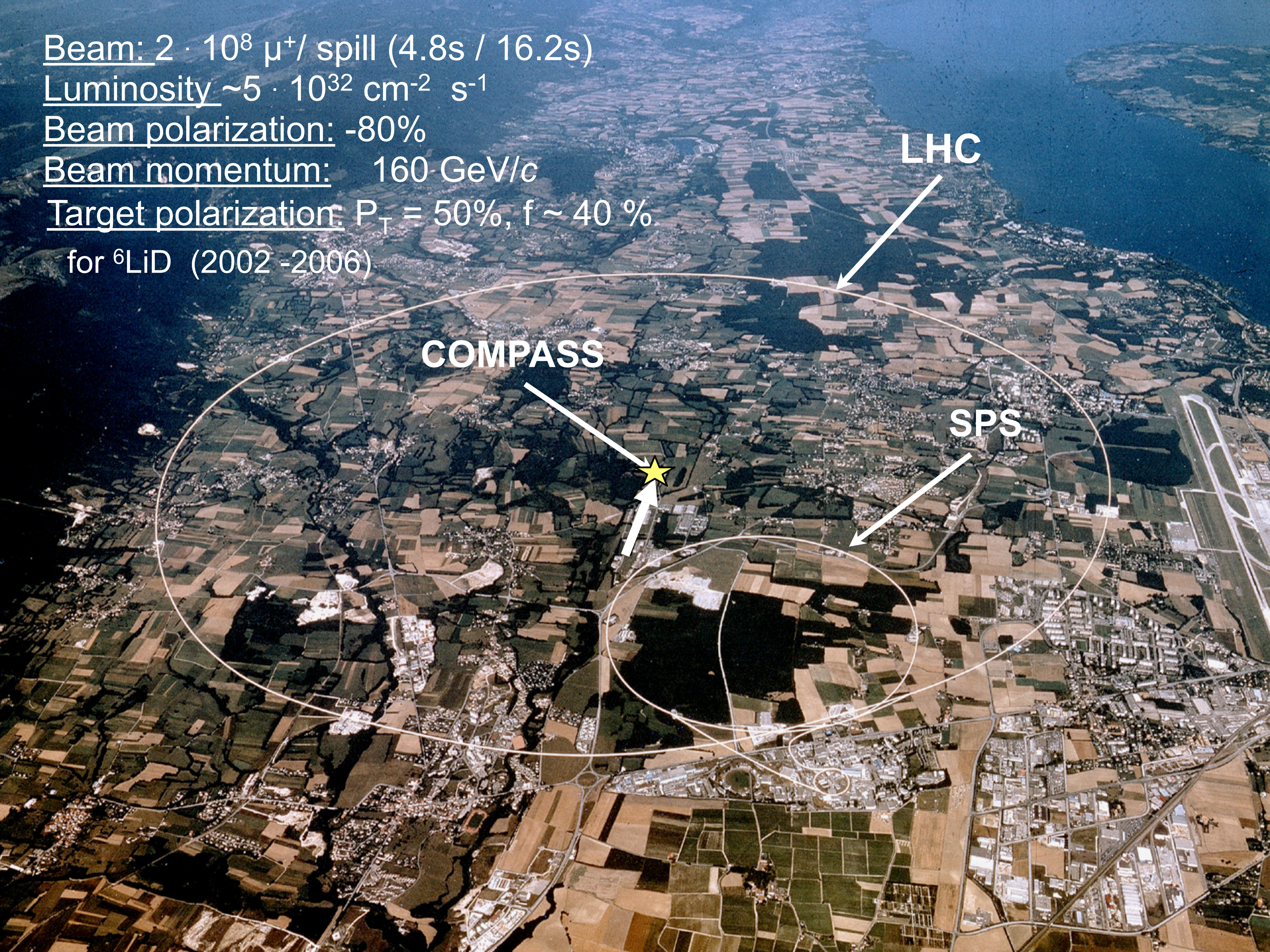

Beam: 2 · 10^8 μ+/ spill (4.8s / 16.2s)
Luminosity ~5 · 10^32 cm^-2 s^-1
Beam polarization: -80%
Beam momentum: 160 GeV/c
Target polarization: P_T = 50%, f ~ 40 %
for 6LiD (2002 -2006)
LHC
COMPASS
SPS

COMPASS Collaboration at CERN

Common Muon and Proton Apparatus

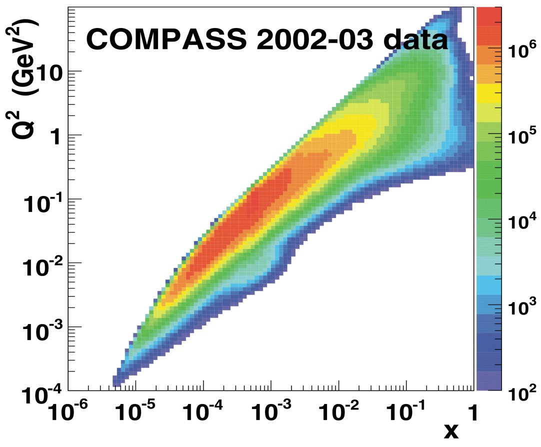
for Structure and Spectroscopy

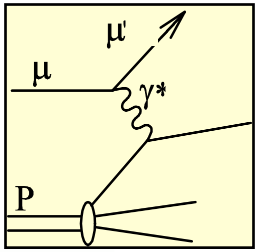
Czech Rep., France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia and CERN

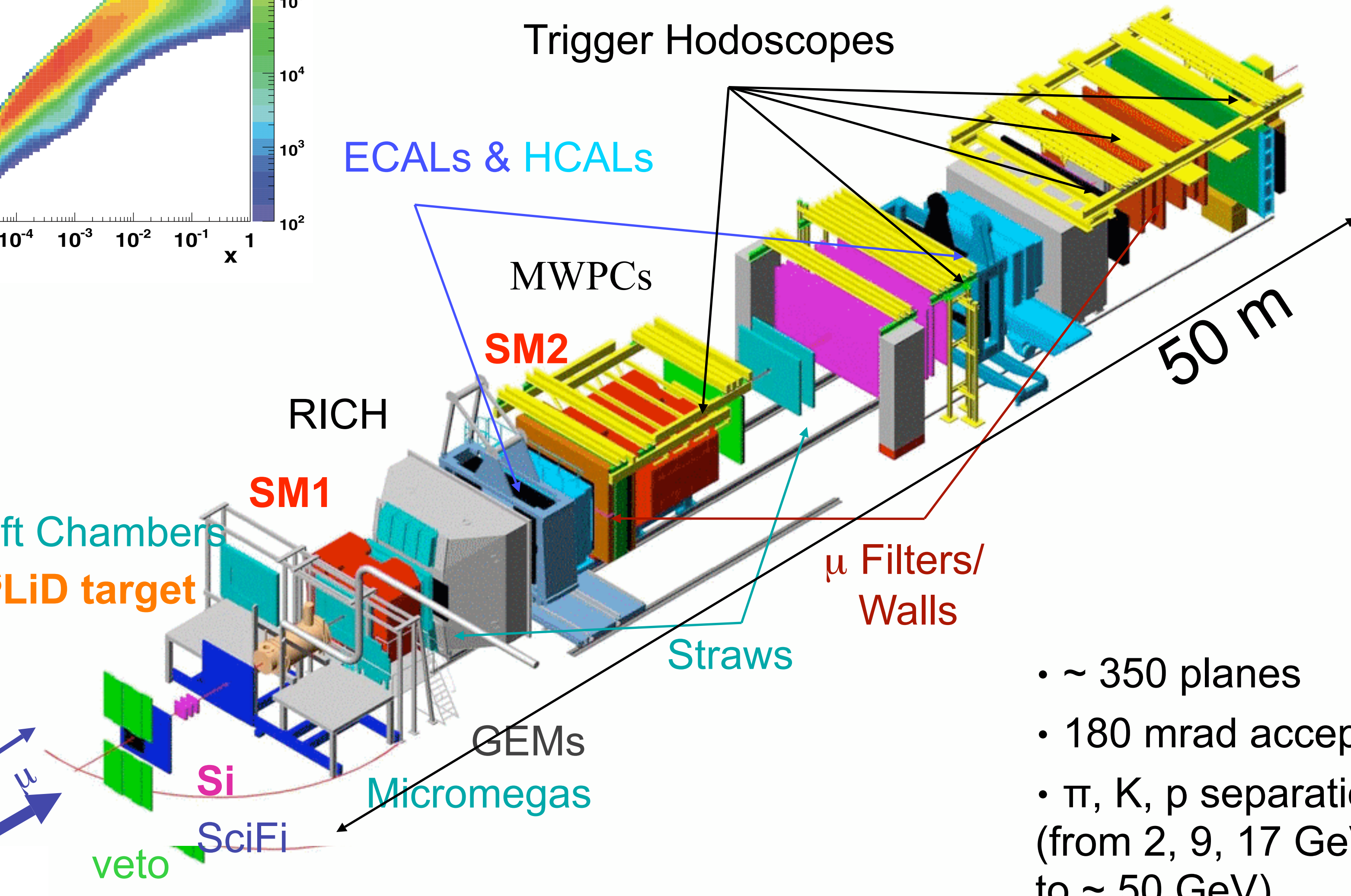
Bielefeld, Bochum, Bonn, Burdwan and Calcutta, CERN, Dubna, Erlangen, Freiburg, Lisbon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw, Yamagata

220 physicists, 26 institutes

COMPASS in muon run
NIM A 577(2007) 455



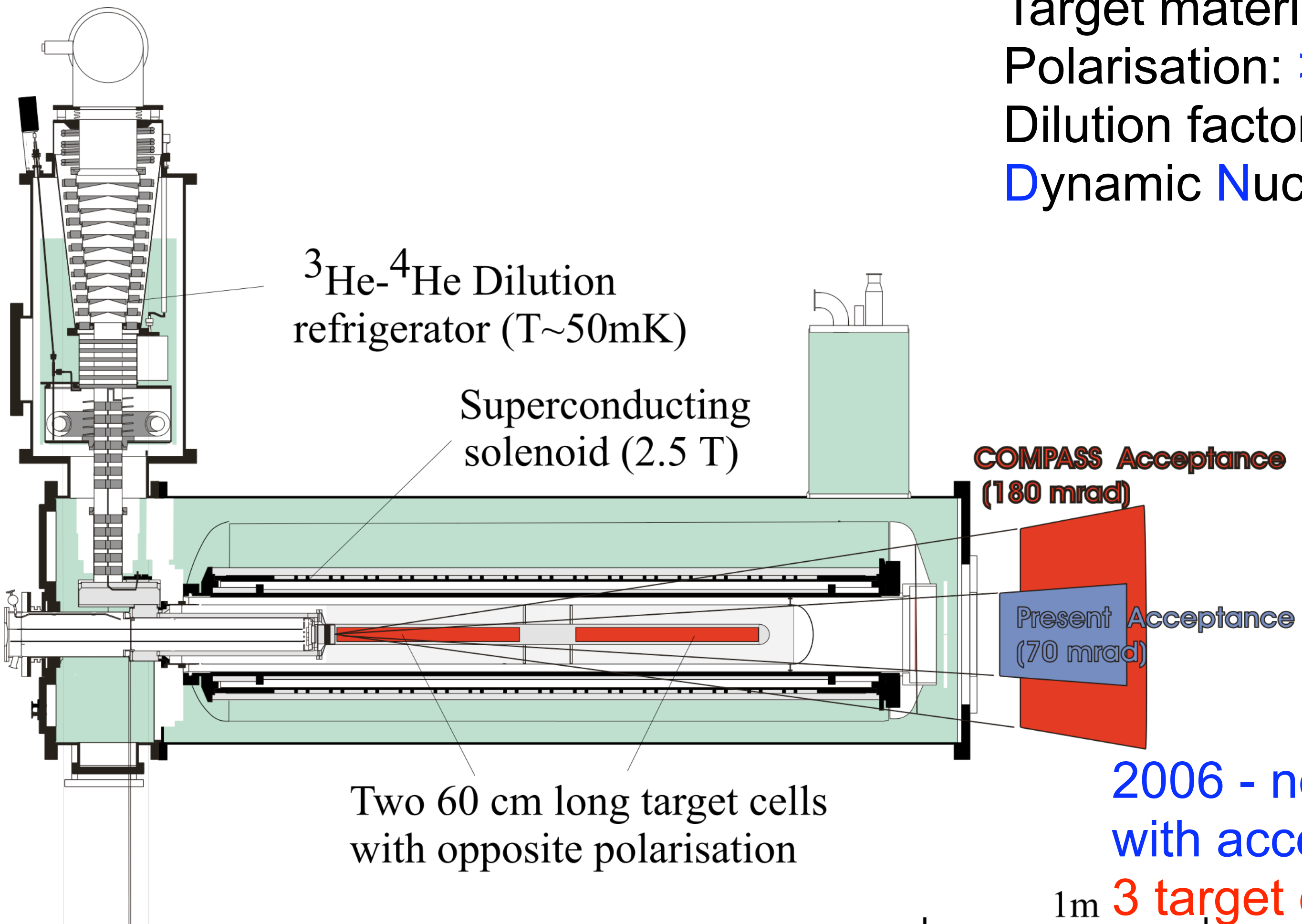




- ~ 350 planes
- 180 mrad acceptance
- π, K, p separation (from 2, 9, 17 GeV up to ~ 50 GeV)

The COMPASS polarised target

Target material: ^{6}LiD
Polarisation: >50%
Dilution factor: ~0.4
Dynamic Nuclear Polarisation



2006 - new solenoid
with acceptance 180 mrad
3 target cells!

2006 Spectrometer upgrades

- Large acceptance target magnet: 70 → 180 mrad
- 3 cell target : reduce false asymmetries
- RICH upgrade : better PID

  MAPMTs in central region

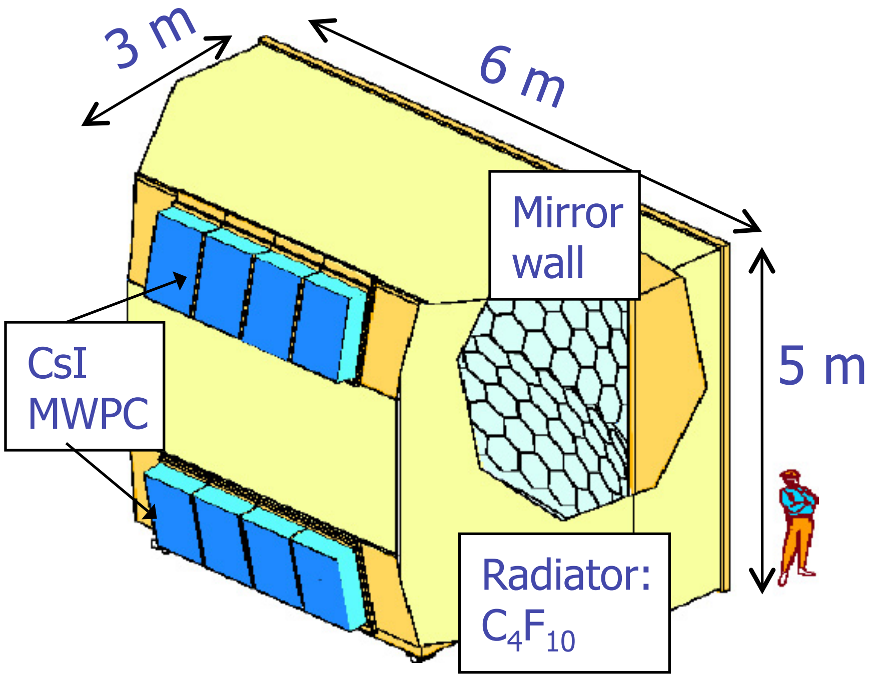
  APV electronics in periphery

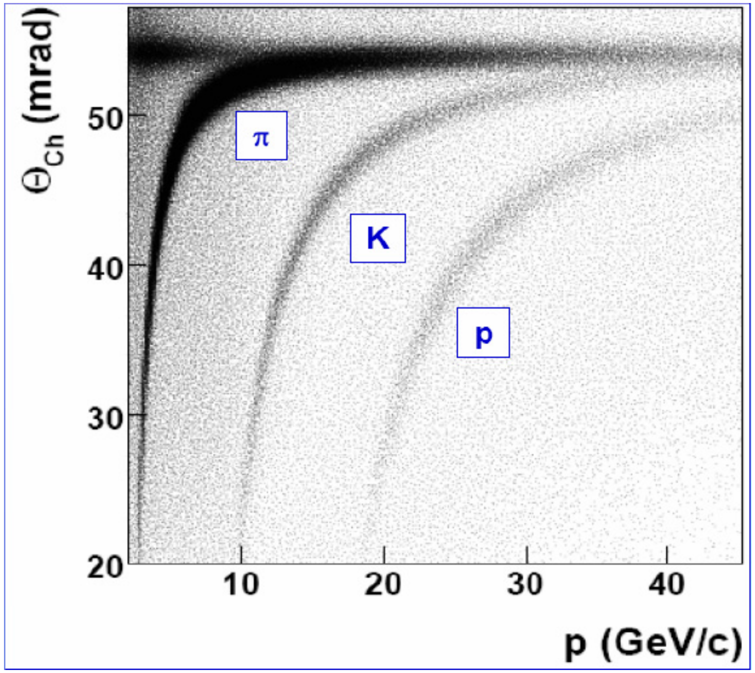
Ring Imaging Cherenkov Detector

Identification of π, K and protons

Cherenkov thresholds: π ≈ 3 GeV/c
K ≈ 9 GeV/c
p ≈ 17 GeV/c

2σ π/K separation at 43 GeV/c

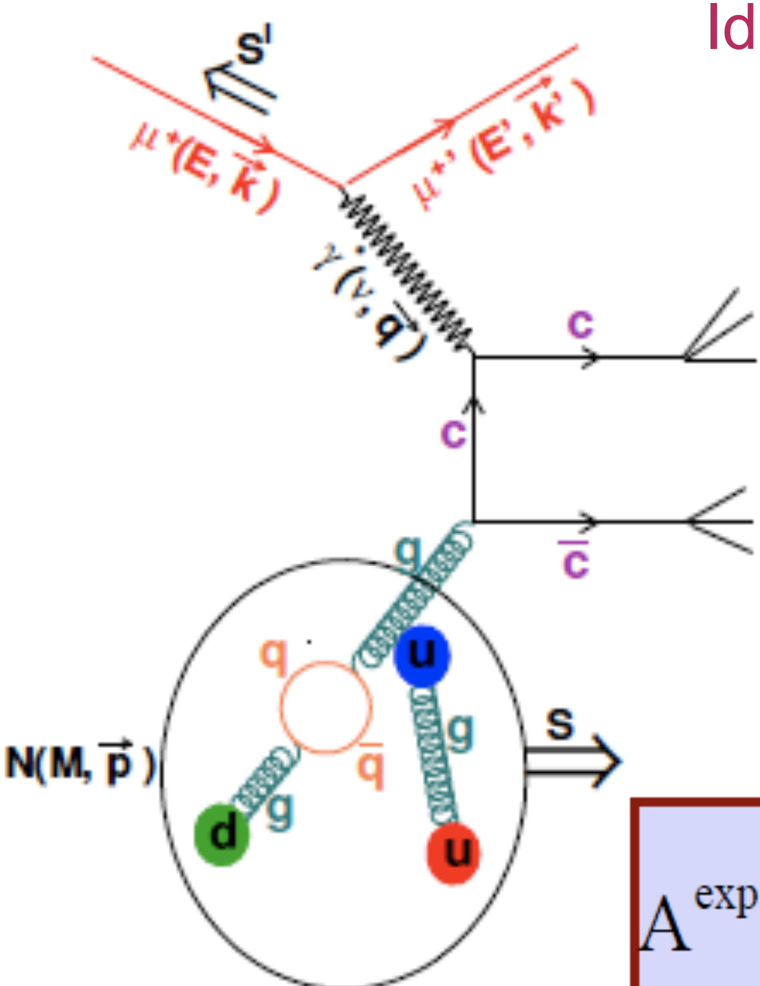




Contents

- COMPASS experiment
- Asymmetries and $\Delta G/G$, introduction to the weighting procedure
- Charmed meson reconstruction at COMPASS
- Signal to background parameterization
- Asymmetries from open-charm
- $\Delta G/G$ in LO approximation from COMPASS main D^0 and D^* channels
- New channels from D^*: π^0 reflection “bump” and “RICH sub-threshold kaons events”
- Neural network approach to signal/background parameterization
- New $\Delta G/G$ result in LO
- Summary and plans

Idea: tagg $\gamma^* g \rightarrow\rightarrow c c_{bar}$ via open-charm production mechanism



$$A^{exp} = \frac{N^u - N^d}{N^u + N^d} = f \cdot P_\mu \cdot P_T \cdot A^{\mu,T} + A^{bg}$$

Number of events

Depolarization from lepton to virtual photon

$$A^{\mu,T} = D \cdot A_1 = D \cdot \boxed{\frac{\sigma^{\rightarrow\leftarrow}_{\gamma,T} - \sigma^{\rightarrow\rightarrow}_{\gamma,T}}{\sigma^{\rightarrow\leftarrow}_{\gamma,T} + \sigma^{\rightarrow\rightarrow}_{\gamma,T}}}$$

Photon-target asymmetry

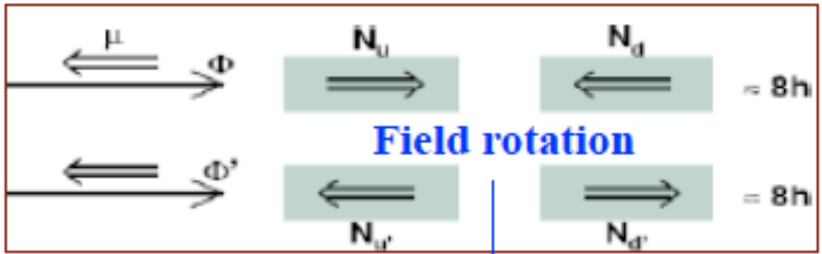
Considering $A_B = 0$

$$\frac{\Delta G}{G} = \frac{1}{2P_T P_\mu f a_{LL} \frac{S}{S+B}} \times \left(\frac{N^u - N^d}{N^u + N^d} + \frac{N^{d'} - N^{u'}}{N^{u'} + N^{d'}} \right)$$

event weight

partonic asymmetry

signal strength of Open-Charm events



equal acceptance for both cells

- **Using** $\boxed{A_1 \overset{\textbf{LO}}{=} \langle a_{LL} \rangle \langle \frac{\Delta G}{G} \rangle \quad \text{with} \quad a_{LL} = \frac{\Delta \sigma^{PGF}}{\sigma^{PGF}}}$

asymmetries are less sensitive to experimental changes than cross section differences

- **Events with small** $(P_\mu \cdot P_T \cdot f \cdot a_{LL} \cdot (S/S+B))$ **factors contain less information about the asymmetry:**
  - Weighting the events with the option choosen minimizes de statistical error

$$\frac{\Delta G}{G} = \frac{1}{2P_T} \times \left(\frac{\omega_u - \omega_d}{\omega_u^2 + \omega_d^2} + \frac{\omega_{u'} - \omega_{d'}}{\omega_{u'}^2 + \omega_{d'}^2} \right) \text{ with a statistical gain} : \frac{\langle \omega^2 \rangle}{\langle \omega \rangle^2}$$

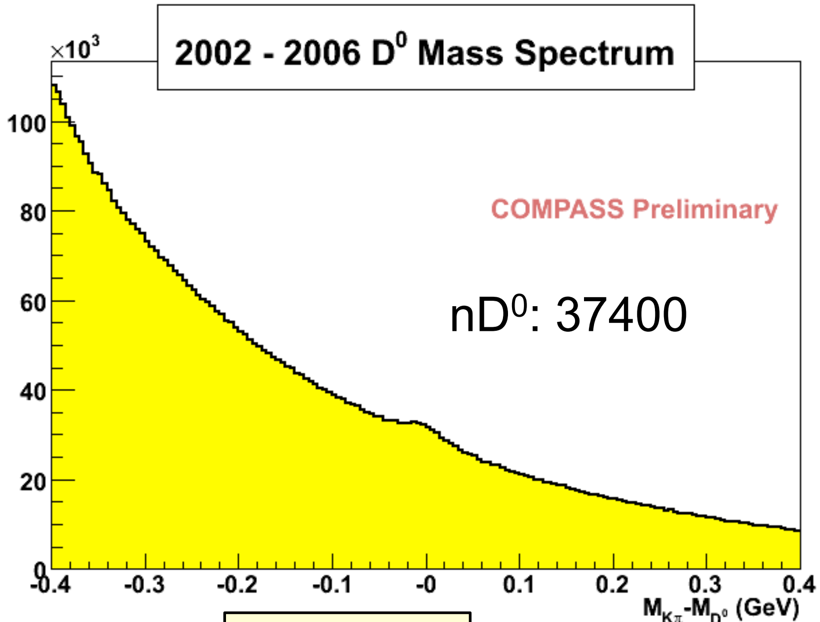
D^0 and D^* meson reconstruction (2002-2006)

- **Events considered** *(resulting from c quarks fragmentation):*
  - $D^0 \rightarrow K\pi$ *(BR: 4%)*
  - $D^* \rightarrow D^0\pi_s \rightarrow K\pi\pi_s$ *(30% D^0 tagged with D^*)*
- **Selection to reduce the combinatorial background:**
  - Kinematical cuts: Z_D, D^0 decay angle, K and π momentum
  - RICH identification: K and π ID + electrons rejected from the π_s sample

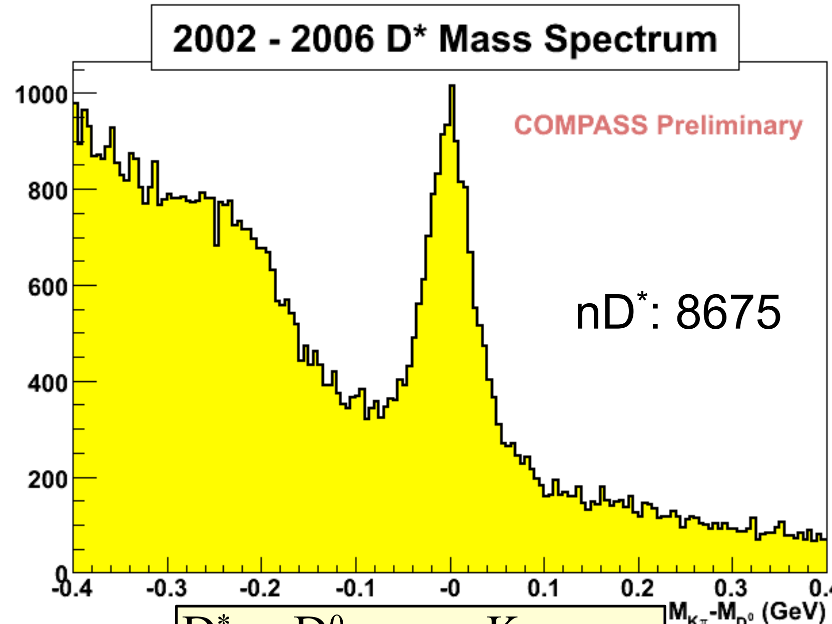
D^0 and D^* meson reconstruction (2002-2006)

Thick target - no D^0 vertex reconstruction

D^0 reconstruction: Kπ invariant mass + cuts on D^0 decay angle + z_D + RICH particle identification (different likehoods)



$$D^0 \rightarrow K + \pi$$

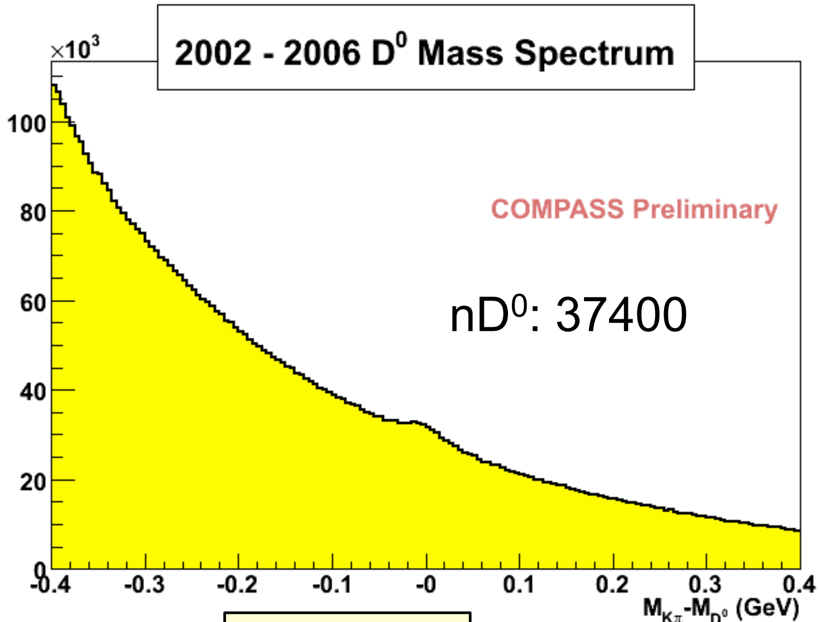


$$D^* \rightarrow D^0 + \pi_s \rightarrow K + \pi + \pi_s$$

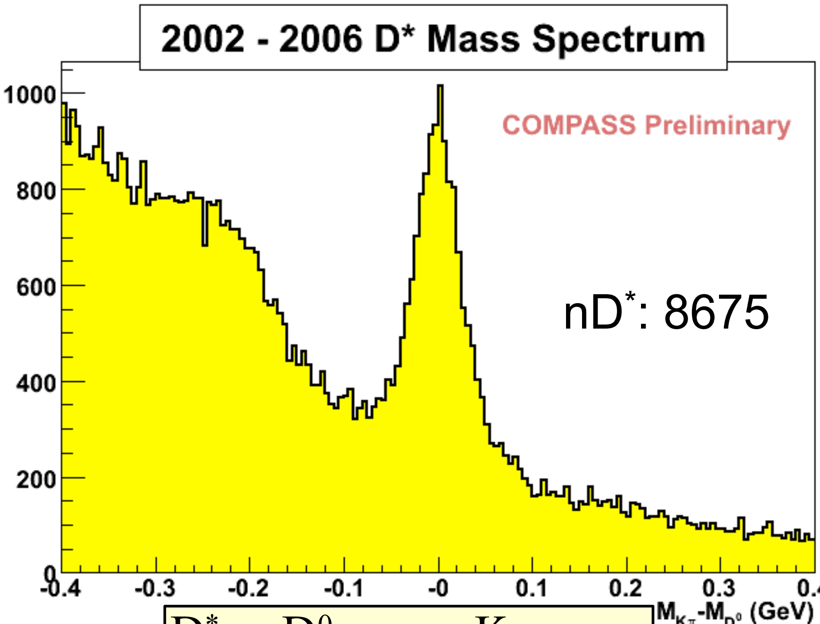
$$\delta\left(\frac{\Delta G}{G}\right) \propto 1 \Big/ \sqrt{\frac{S}{S+B} \times S}$$

D^0 and D^* meson reconstruction (2002-2006)

Thick target - no D^0 vertex reconstruction
D^0 reconstruction: $K\pi$ invariant mass + cuts on D^0 decay angle + z_D + RICH particle identification (different likehoods)



$D^0 \rightarrow K + \pi$



$D^* \rightarrow D^0 + \pi_s \rightarrow K + \pi + \pi_s$

$$\delta\left(\frac{\Delta G}{G}\right) \propto 1 \Big/ \sqrt{\frac{S}{S+B} \times S}$$

Due to weighted method spectra are not optimized!

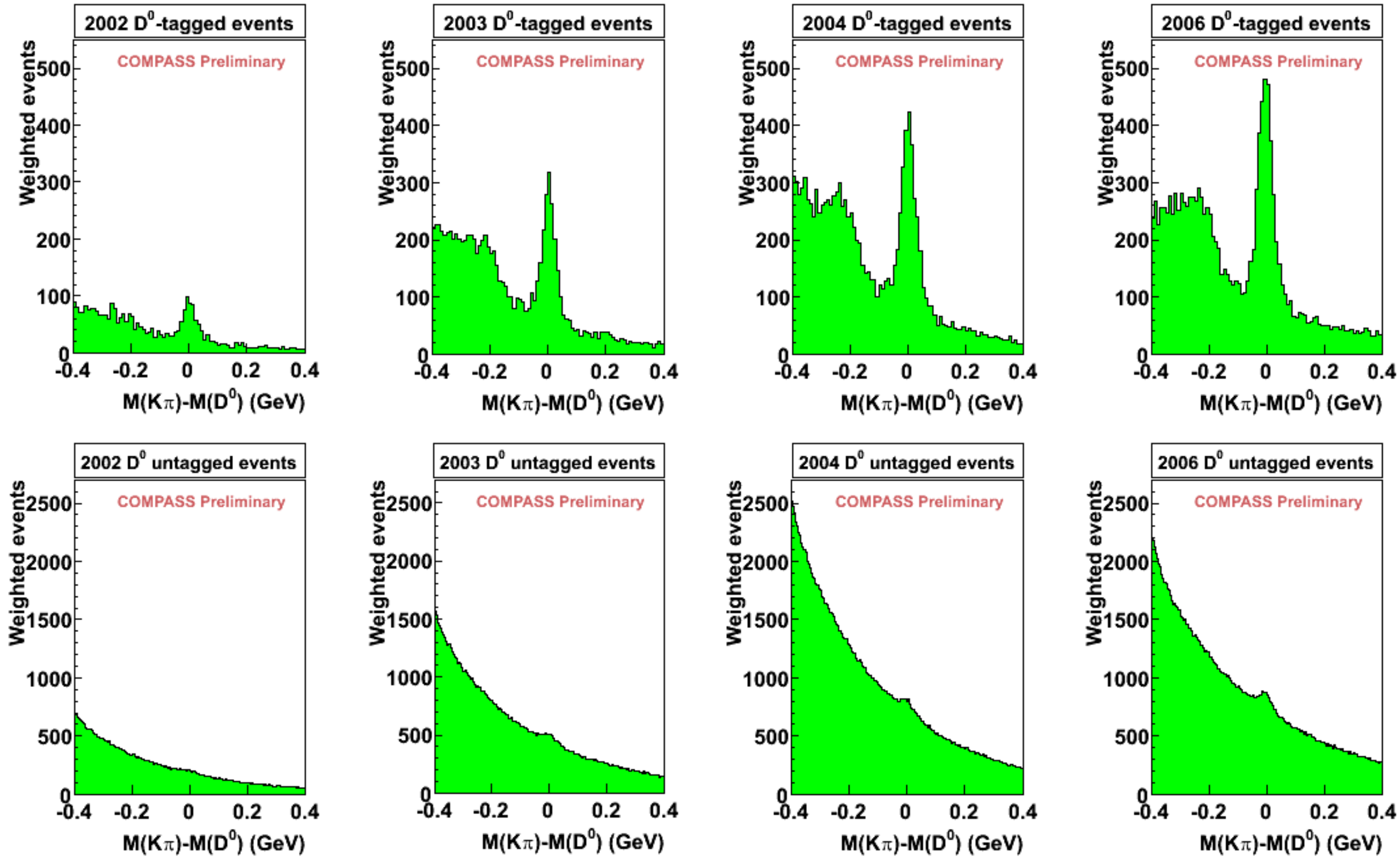
Open-charm signal - per year

Kπ invariant mass weighted spectra

2002	2003	2004	2006
0.43 fb $^{-1}$	0.58 fb $^{-1}$	0.92 fb $^{-1}$	0.85 fb $^{-1}$

D^*

D^0



$\gamma^* N$ asymmetries

$$A_{\exp} = P_B P_T f \left[R_{PGF} D A^{\gamma N \to D X} + (1 - R_{PGF}) A_{bkg} \right]$$

$$\frac{1}{P_T} \frac{\sum w^{\overleftarrow{\Rightarrow}} - \sum w^{\overleftarrow{\Rightarrow}}}{\sum w^{\overleftarrow{\Rightarrow}} + \sum w^{\overleftarrow{\Rightarrow}}} = A^{\gamma N} \qquad w = f P_B \frac{S}{S+B} D$$

Weighting brings significant improvement due to large variations of D and R_{PGF}=S/(S+B) in phase-space

Asymmetries $A^{\gamma^* N \to DX}$ calculated in (p_T , E_D bins)

Bins chosen such that dispersion in a_{LL}/D is small; dependence on kinematic factors y, D,… is also weak.

Extraction of ΔG at LO

- Model independent asymmetries were extracted from data only

$$A_{\exp} = P_B P_T f\left[R_{PGF} D A^{\gamma N \to DX} + (1 - R_{PGF}) A_{bkg}\right]$$

- $\dfrac{\Delta g}{g}$ can be extracted using a_{LL}^{PGF} calculated at LO :

$$A_{\exp} = P_B P_T f\left[R_{PGF}\, a_{LL}^{PGF} \frac{\Delta g}{g} + (1 - R_{PGF}) A_{bkg}\right]$$

- Similar analysis, but with weight $w = f\, P_B \dfrac{S}{S+B} a_{LL}$

instead of $w = f\, P_B \dfrac{S}{S+B} D$

Σ=S/(S+B) weighting

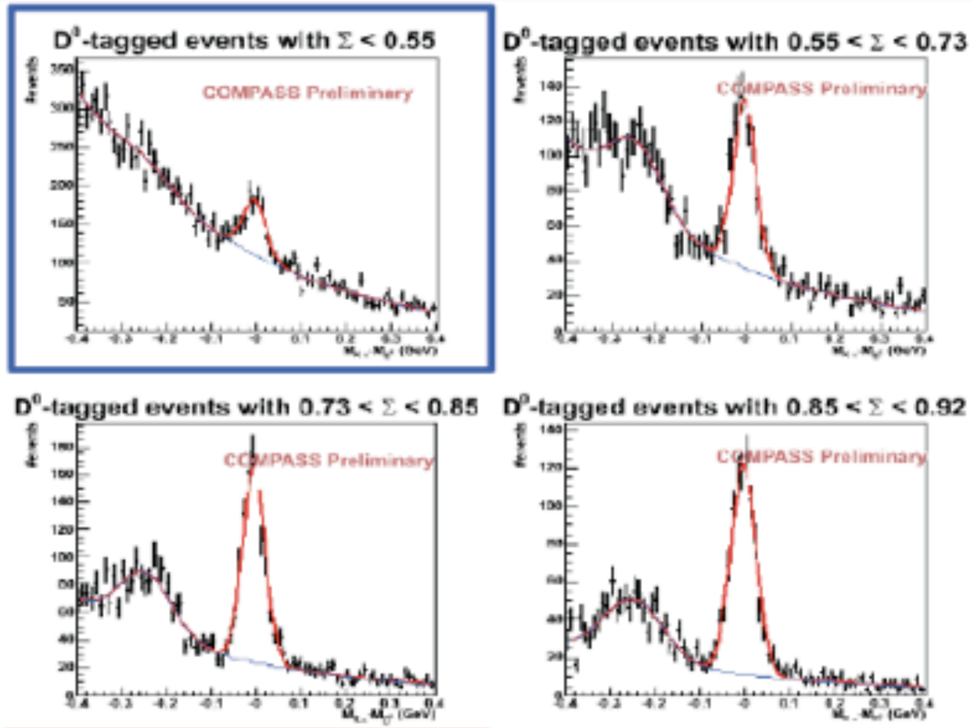
- Σ=S/(S+B) probability for an event to be PGF. Parameterized as function of kinematics & RICH response. Given event by event
- Event weight with 10 variables built on data only
- Gain from weighting + possibility to loosen cuts:

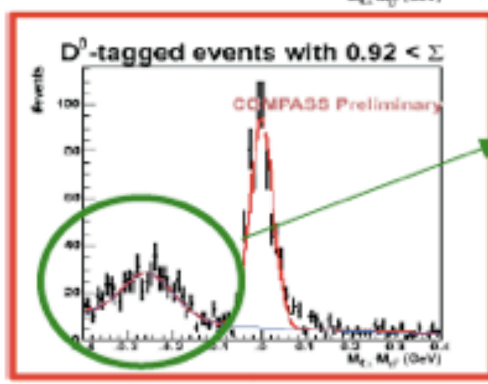
  +45% for D^0 and 15% for D^*

Σ (=$S/S+B$) as an Open-Charm event probability

Why is better to have (S/S+B) for every event?

- **Events with small $\Sigma \Rightarrow$ low weight**
  - Mostly combinatorial background selected
- **With Σ in the weight, the kinematical cuts can be loose:**
  - More background events
  - Preserve signal events
- **Events with large $\Sigma \Rightarrow$ high weight**
  - Mostly Open-Charm events selected



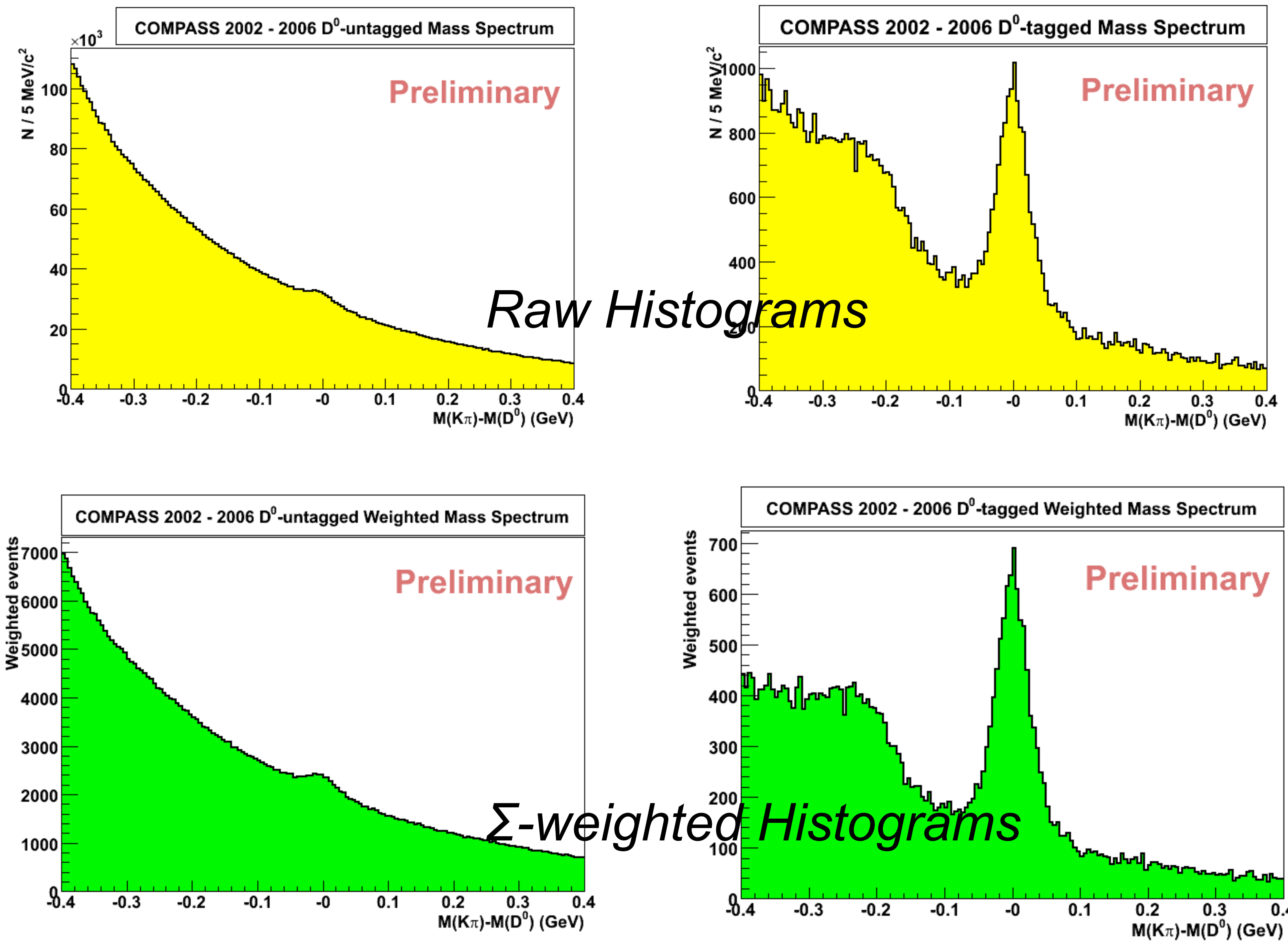


Possibility to include a new Open-Charm channel in the analysis for statistical error improvement

How to parameterize Σ ?

- **A function to build Σ_p = S/B is defined, and parameterized for every event:**
  - Σ_p is built *(iteratively)* over some kinematic variables and RICH response:
    - $(\Sigma_p)_{initial} = 1$
    - Mass spectra is divided in bins of each variable *(binning needed for statistical gain)*
    - Fit all D^0 and D^* mass spectra inside each bin of each variable
    - Σ_p is ajusted *(for every event inside each bin)* to $(S/B)_{fit}$
  - After convergence, parameterization is checked:
    - No artificial peak produced in wrong charge mass spectra
  - Mass dependence $\Rightarrow$ Included in Σ after convergence of Σ_p
    - $(\Sigma = \Sigma_p / \Sigma_p + 1)$ in the weight $\longrightarrow$ **probability for a given event to be background or Open-Charm**

Invariant mass of Kπ pairs - S/(S+B) weighting

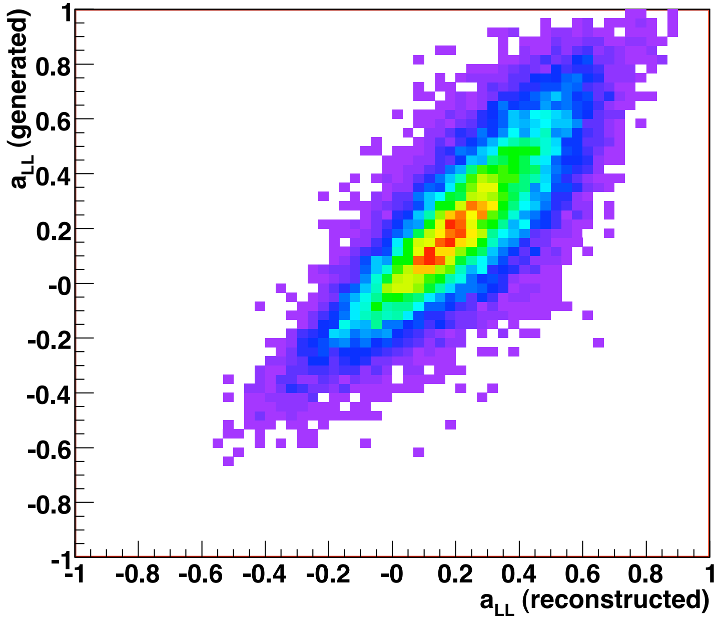


Partonic *(muon-gluon)* asymmetry a_{LL}

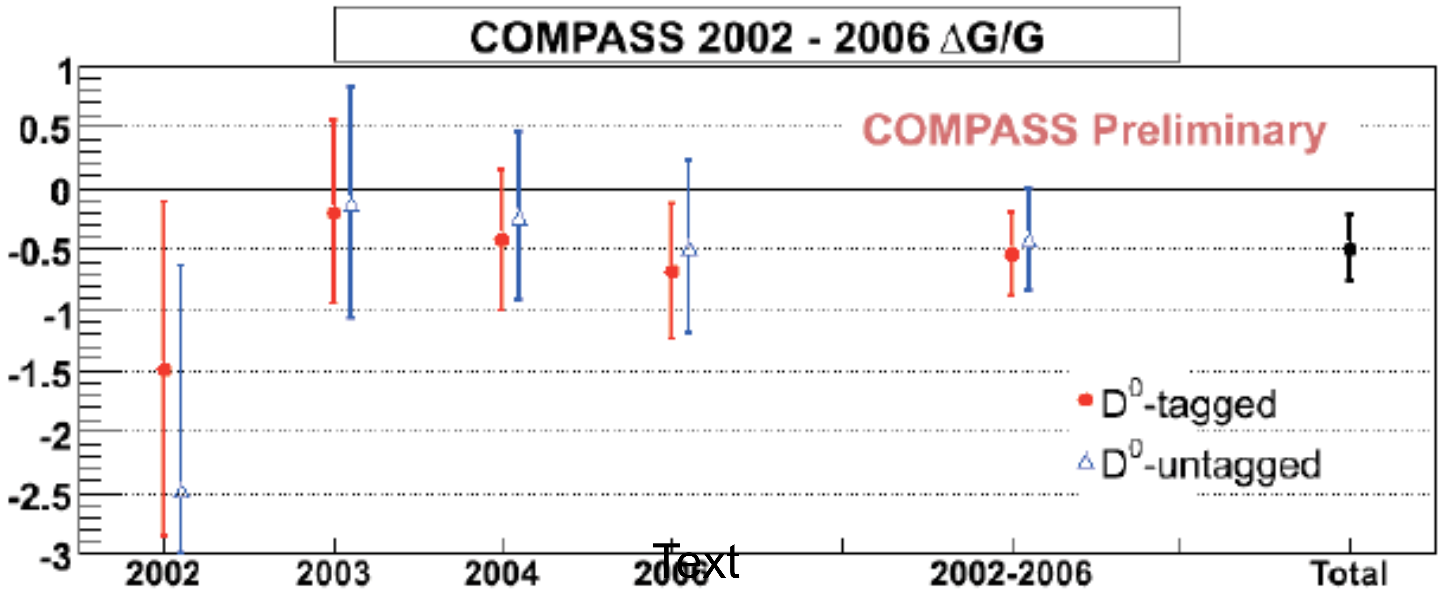
- a_{LL} **is dependent on full knowlege of partonic kinematics:**
  - $$a_{LL} = \frac{\Delta\sigma^{PGF}}{\sigma_{PGF}}(y, Q^2, x_g, z_C, \phi)$$
  - Can't be experimentally obtained! $\Rightarrow$ only one charmed meson is reconstructed

- a_{LL} is obtained from Monte-Carlo *(in LO)*, to serve as input for a Neural Network parameterization on reconstructed kinematical variables: y, x_{Bj}, Q^2, z_D and $p_{T,D}$

- 82% correlation NN/MC
- very large dispersion of values, even change of sign: weighting essential



Open charm : D^0 + D* Result



$$\Delta G/G = -0.49 \pm 0.27\ (\mathrm{stat}) \pm 0.11\ (\mathrm{syst})$$

Systematics :

Source	D^0	D*
Beam polar	0.025	0.025
Target polar	0.025	0.025
Dil. Fact.	0.025	0.025
False asymmetry	0.05	0.05
Signal extraction (Σ)	0.07	0.01
a_{LL} (charm mass)	0.05	0.03
TOTAL	**0.11**	**0.07**

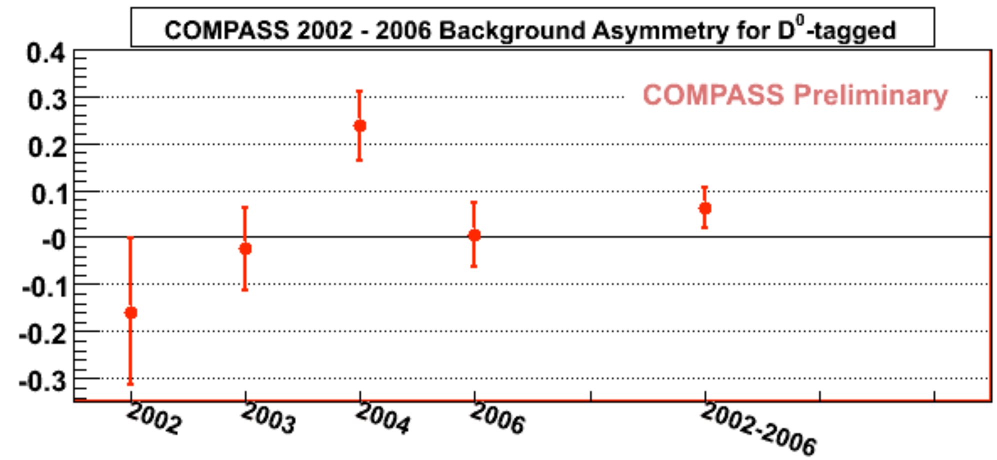
$$\langle x_g \rangle = 0.11^{+0.11}_{-0.05}$$

$$\langle \mu^2 \rangle = 13\, GeV^2$$

published:
PLB676(2009)31

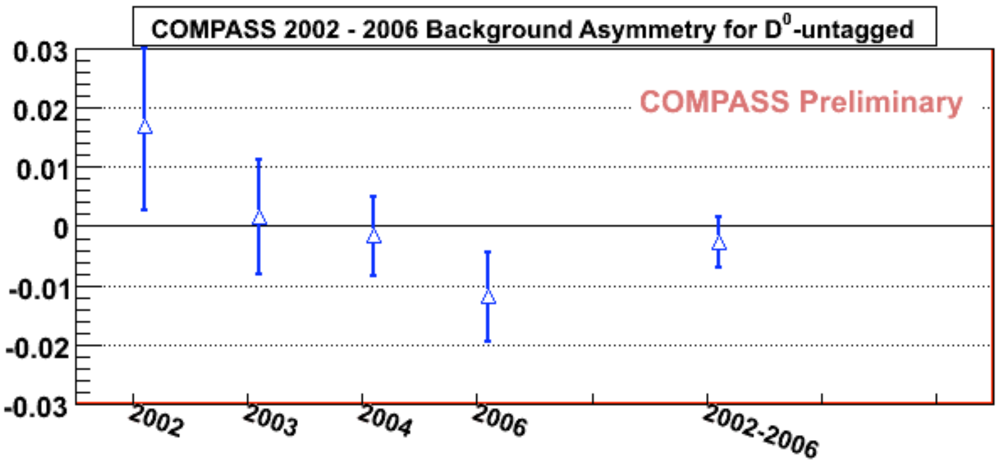
Background asymmetry

Background and signal asymmetries extracted simultaneously



D^*

$A_{bkg} = 0.062 \pm 0.042$



D^0

$A_{bkg} = 0.0026 \pm 0.0043$

Asymmetries in bins in p_T and E of D^0

Table 2
The asymmetries $A^{\gamma N \to D^0 X}$ in bins of $p_T^{D^0}$ and E_{D^0} for the D^0 and D^* sample combined, together with the averages of several kinematic variables. Only the statistical errors are given. The relative systematic uncertainty is 20% which is 100% correlated between the bins.

Bin limits		$A^{\gamma N \to D^0 X}$	$\langle y \rangle$	$\langle Q^2 \rangle$ $(\mathrm{GeV}/c)^2$	$\langle p_T^D \rangle$ (GeV/c)	$\langle E_D \rangle$ (GeV)	$D(\langle X \rangle)$	$a_{LL}(\langle X \rangle)$
p_T^D (GeV/c)	E_D (GeV)							
0–0.3	0–30	-1.34 ± 0.85	0.47	0.50	0.19	24.8	0.57	0.37
0–0.3	30–50	-0.27 ± 0.52	0.58	0.75	0.20	39.2	0.70	0.48
0–0.3	>50	-0.07 ± 0.66	0.67	1.06	0.20	60.0	0.80	0.61
0.3–0.7	0–30	-0.85 ± 0.51	0.47	0.47	0.50	25.1	0.56	0.26
0.3–0.7	30–50	0.09 ± 0.29	0.58	0.65	0.51	39.4	0.71	0.34
0.3–0.7	>50	-0.20 ± 0.37	0.67	0.68	0.50	59.6	0.80	0.46
0.7–1	0–30	-0.47 ± 0.56	0.48	0.53	0.85	25.2	0.58	0.13
0.7–1	30–50	-0.49 ± 0.32	0.58	0.66	0.85	39.1	0.70	0.17
0.7–1	>50	1.23 ± 0.43	0.68	0.73	0.84	59.4	0.81	0.26
1–1.5	0–30	-0.87 ± 0.48	0.50	0.49	1.21	25.7	0.60	0.01
1–1.5	30–50	-0.24 ± 0.25	0.60	0.62	1.22	39.5	0.73	0.00
1–1.5	>50	-0.18 ± 0.34	0.69	0.77	1.22	59.3	0.83	0.04
>1.5	0–30	0.83 ± 0.71	0.52	0.51	1.77	26.2	0.63	-0.13
>1.5	30-50	0.18 ± 0.28	0.61	0.68	1.87	40.0	0.74	-0.20
>1.5	>50	0.44 ± 0.33	0.71	0.86	1.94	59.9	0.84	-0.24

weighted!

$$w = f \, P_B \frac{S}{S+B} D$$

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More contributions from the D^* channel

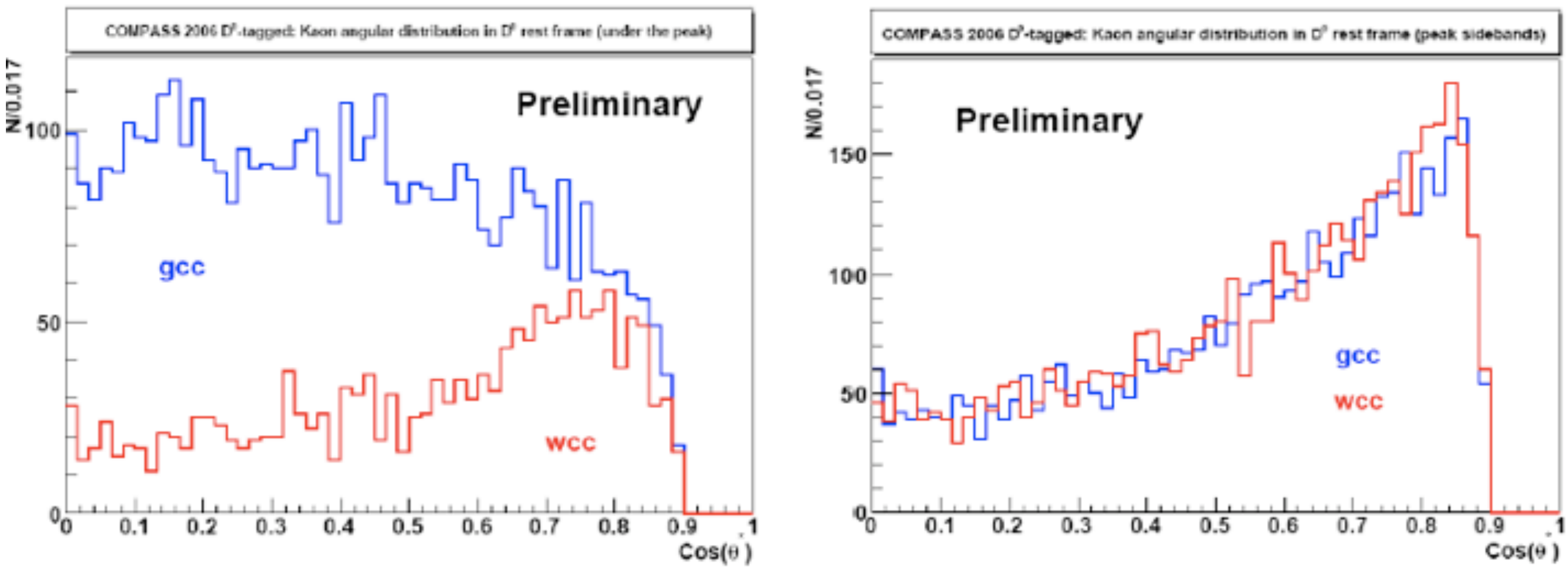
- **Because the channel is very clean from background contamination** *(due to a 3-body mass cut)*, **the following contributions can be added:**
  - π^0 reflection "bump": $\mathbf{D^0 \rightarrow K\pi\pi^0} \Rightarrow$ Mass window increased to $\pm$ **600 MeV/c^2** to obtain a better fit on the bump!
  - RICH sub-threshold Kaons events: Include candidates with no positive pion or electron ID

- **Signal strength parameterization** *($\Sigma = S/(S+B)$)*:
  - **Problem**:
    - Low purity samples with low statistics $\Rightarrow$ Very difficult to build Σ in several bins of several variables
  - **Solution**:
    - Multi-dimentional parameterization using a Neural Network *(all kinematic and RICH dependences taken into account at same time)*

Neural Network qualification of events

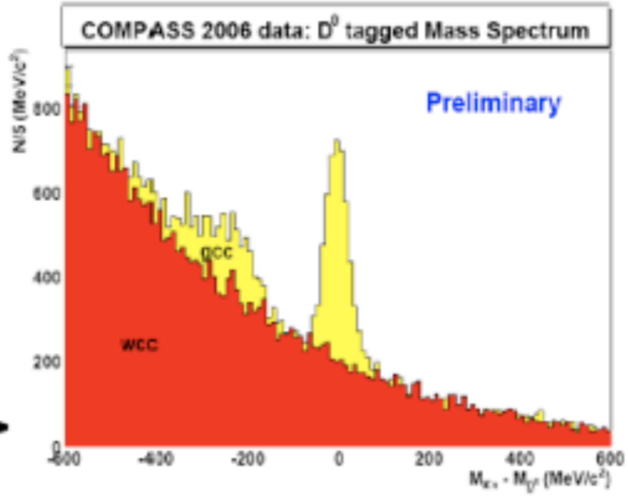
- **Two real data samples** *(with same cuts)* **are compared by the Neural Network** *(giving as input some kinematic variables as a learning vector)*:
  - **Signal model** $\rightarrow$ **gcc** $= K^{+}\pi^{-}\pi_{s}^{-} + K^{-}\pi^{+}\pi_{s}^{+}$ *(D^{*} spectrum: signal + bg.)*
  - **Background model** $\rightarrow$ **wcc** $= K^{+}\pi^{+}\pi_{s}^{-} + K^{-}\pi^{-}\pi_{s}^{+}$
- **If the background model is good enough:** Net is able to distinguish the signal from the combinatorial background on a event by event basis!

Example of a good learning variable

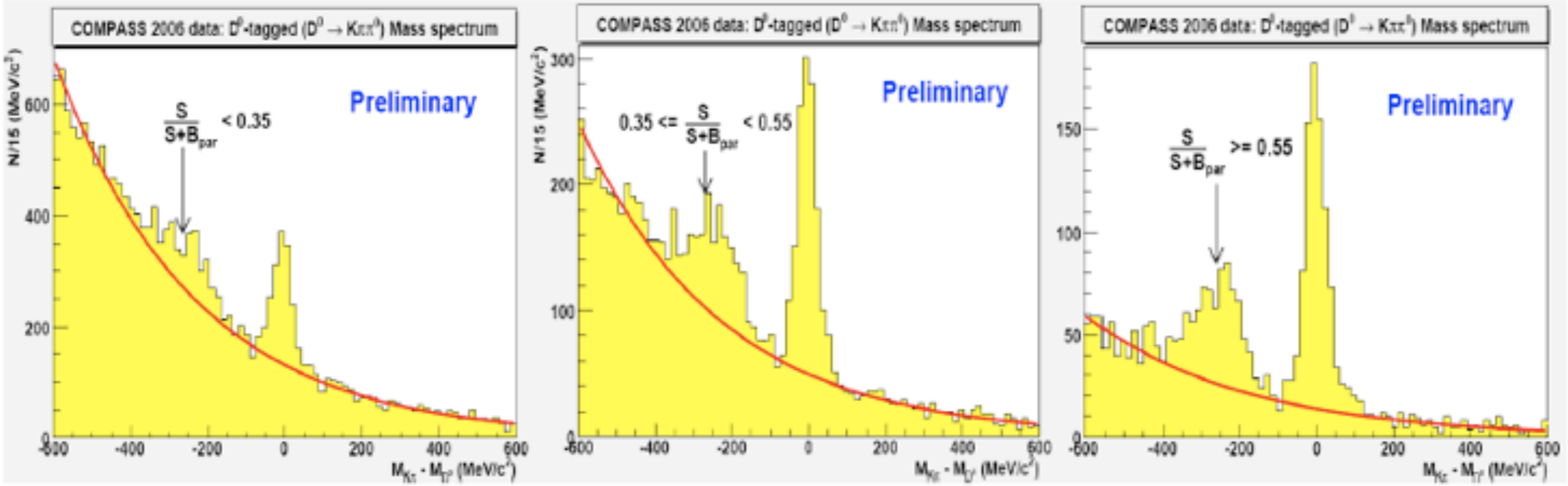


π^0 reflection "bump": Probability behaviour

- Σ is built in the same way as for main channels, **BUT**:
  - Only 1variable is used: Neural Network output
    - Sorts the events according to similar kinematic dependences *(thus improving our statistical precision)*
    - Results from 2 real data samples comparison, in a mass window around the meson mass

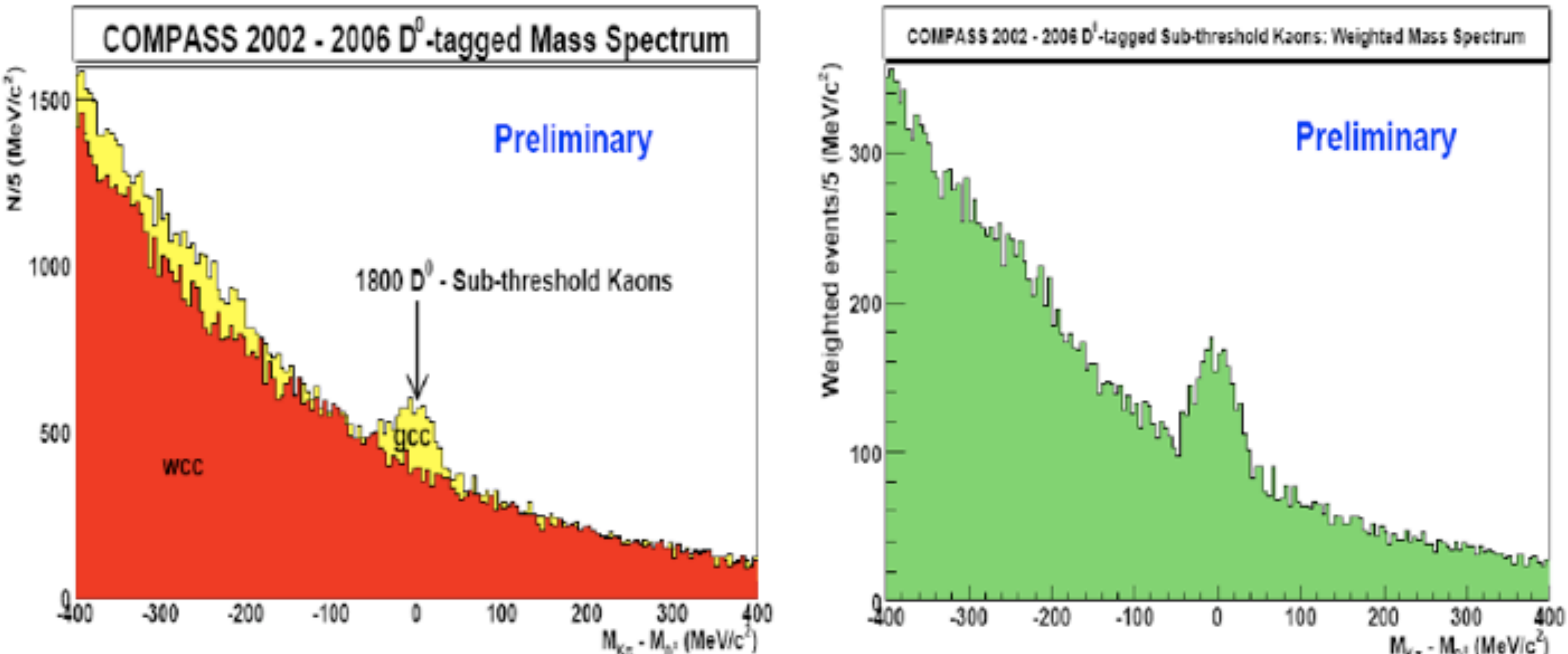


π^0 reflection in bins of Σ



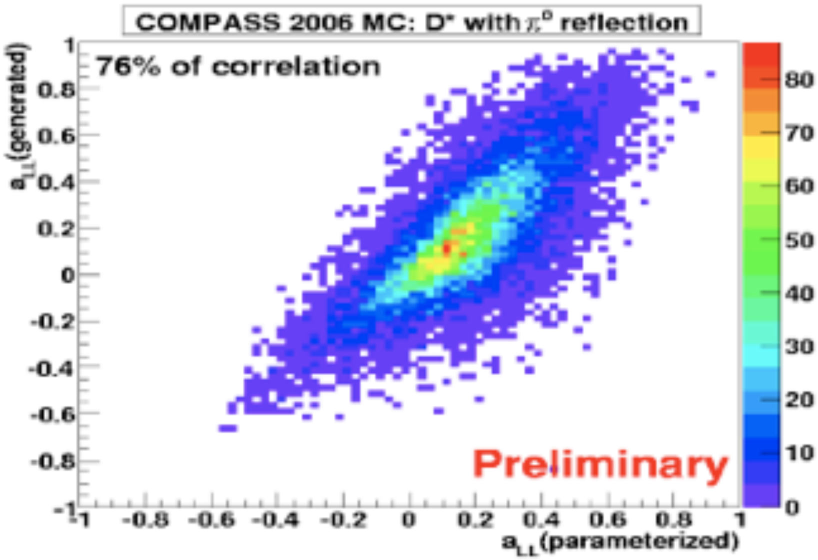
Sub-threshold Kaons: S/B improvement

- Σ is built in the same way as for π^0 reflection "bump"!
  - In plots below, the gain introduced by this parameterization can clearly be seen



Preliminary results including all channels

- For all π^0 decays from a D^0 (*" bump"*), a specific parameterization for the partonic asymmetry (a_{LL}) was used



- New channels contributions to $\Delta G/G$:

$\Delta G/G$: -0.15 ± 0.63
Bg. Asymmetry: 0.02 ± 0.03

→ 2002–2006 data: π^0 reflection "bump"

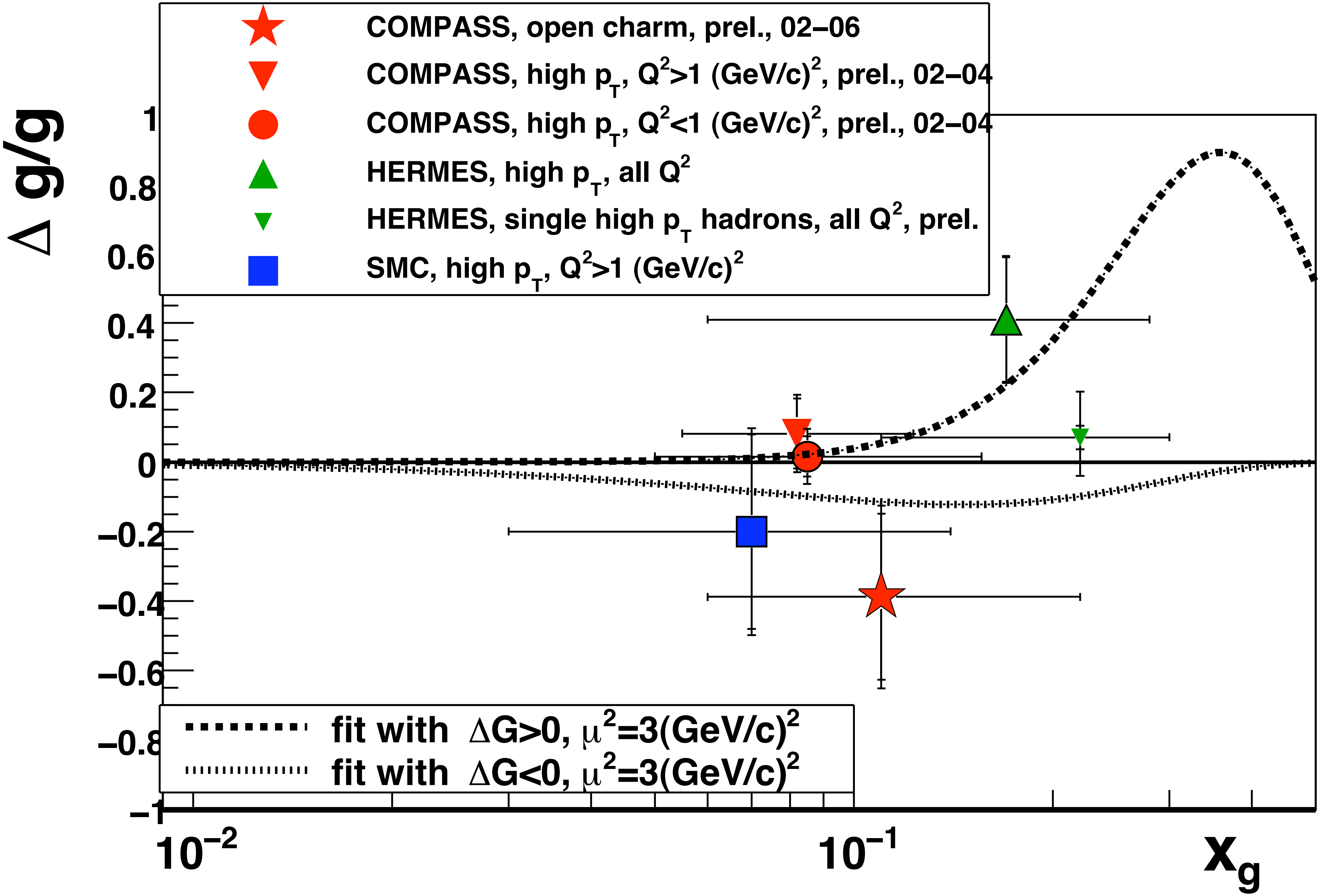
$\Delta G/G$: 0.57 ± 1.02
Bg. Asymmetry: -0.04 ± 0.05

→ 2002–2006 data: Sub-threshold Kaons

- **Final result** *(no systematic contribution is available yet for the new channels)*:

$$\frac{\Delta G}{G} = -0.39 \pm 0.24\ (stat) \quad @ \langle x_g \rangle = 0.11,\ \langle \mu^2 \rangle = 13\ \text{GeV}^2$$

10 % improvement in our statistical significancy



COMPASS, open charm, prel., 02–06
COMPASS, high p_T, $Q^2>1$ (GeV/c)^2, prel., 02–04
COMPASS, high p_T, $Q^2<1$ (GeV/c)^2, prel., 02–04
HERMES, high p_T, all Q^2
HERMES, single high p_T hadrons, all Q^2, prel.
SMC, high p_T, $Q^2>1$ (GeV/c)^2
fit with $\Delta G>0$, $\mu^2=3$(GeV/c)^2
fit with $\Delta G<0$, $\mu^2=3$(GeV/c)^2
$\Delta g/g$
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
10^{-2}
10^{-1}
x_g

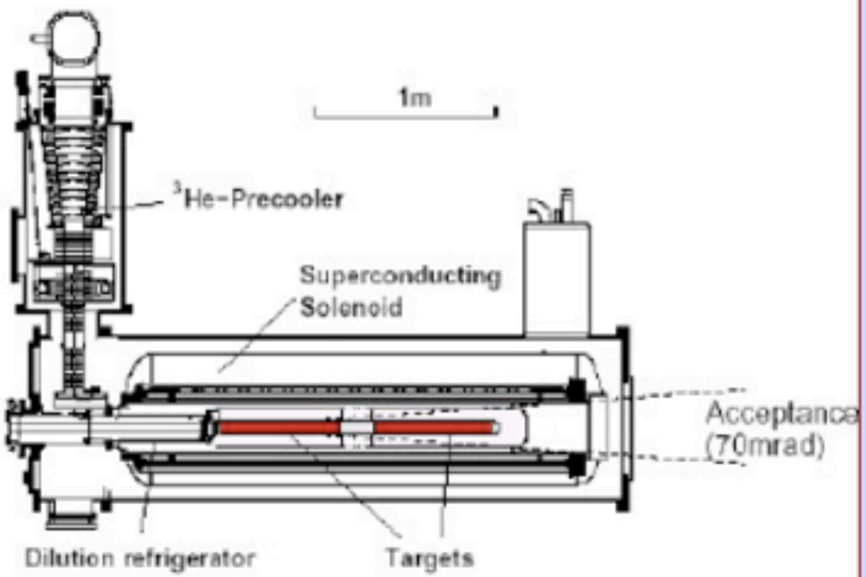
Summary

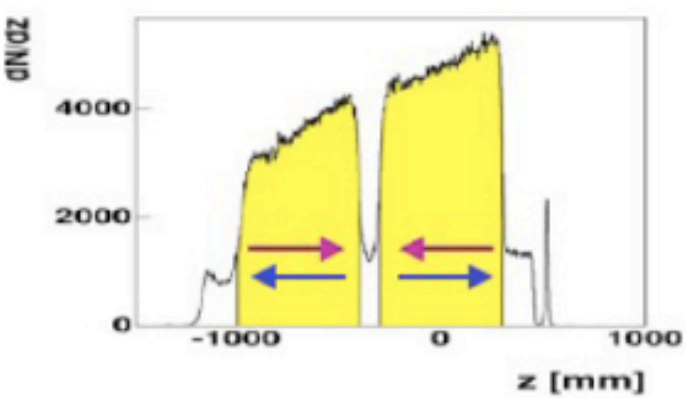
- Small value of $\Delta G/G$ is preferred - $\Delta G/G$ compatible with 0 within 2σ
- Under study:
  - pure NN approach (fit independent)
  - 2008 data (proton)
  - others channels (4 particles from decay)
  - NLO analysis

Spares

Polarised target

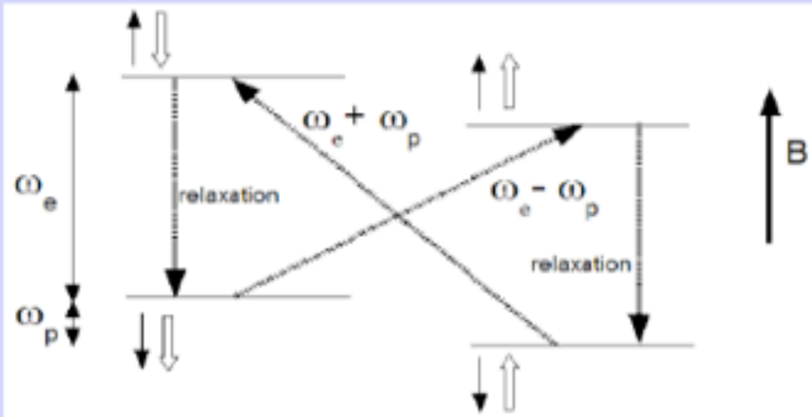
- Target material: ^{6}LiD
- Solenoid field: 2.5 T
- Dilution factor: f ~ 0.4
- Polarisation: $P_T > 50\%$
- ^{3}He/^{4}He: T_{min} ~ 50 mK





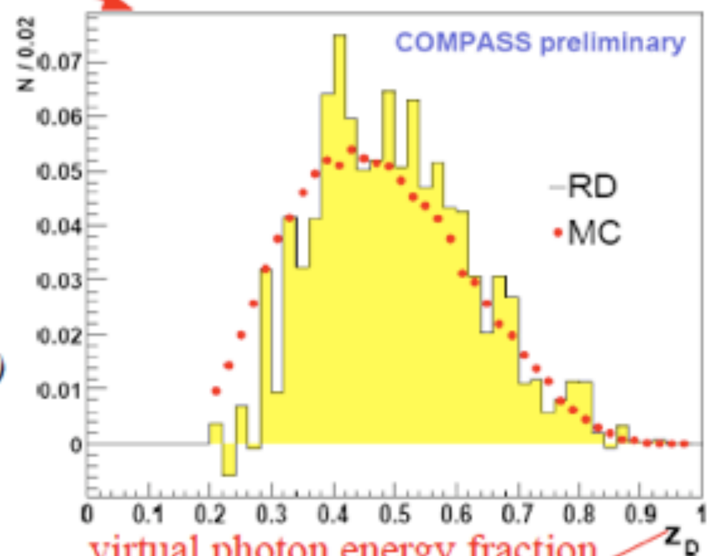
Dynamic nuclear polarisation:

- High electron polarisation *(high magnetic moment)*
- Microwave irradiation of material, for simultaneous flip of electron and nucleon spin
- After spin flip, electron relaxates to lower energy state
- Nucleon has long relaxation time *(low magnetic moment)*

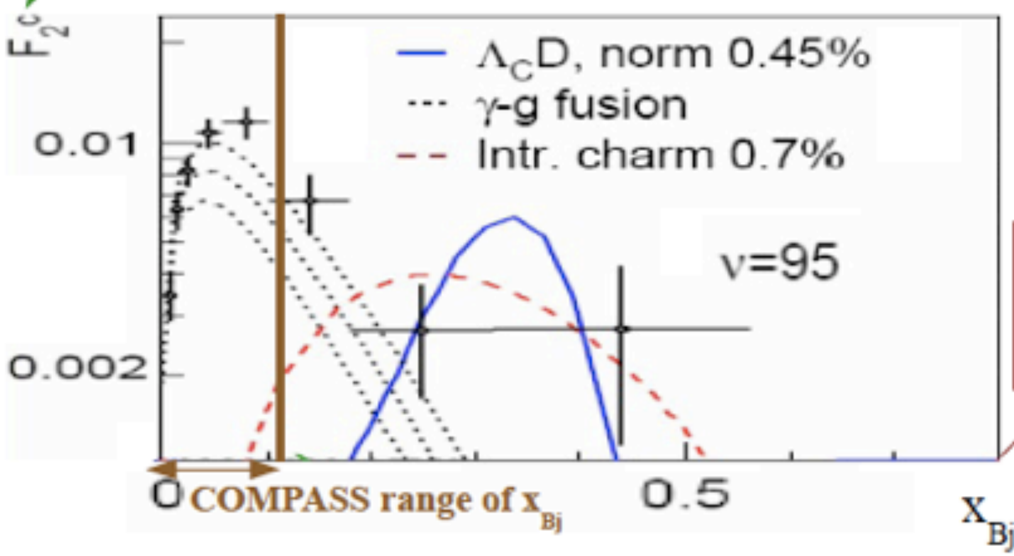


Why measure gluon spin from Open-Charm?

- $c\bar{c}$ production is dominated by the PGF process, and <u>free from physical background</u> *(ideal for probing gluon polarisation)*
  - In our center of mass energy, the contribution from intrinsic charm *(c quarks not coming from hard gluons)* in the nucleon is negligible
  - Perturbative scale set by charm mass $4m_c^2$
  - Nonperturbative sea models predict at most 0.7% for intrinsic charm contribution
    - Expected at high x_{Bj} *(compass x_{Bj} < 0.1)*
  - $c\bar{c}$ supressed during fragmentation *(at our energies)*



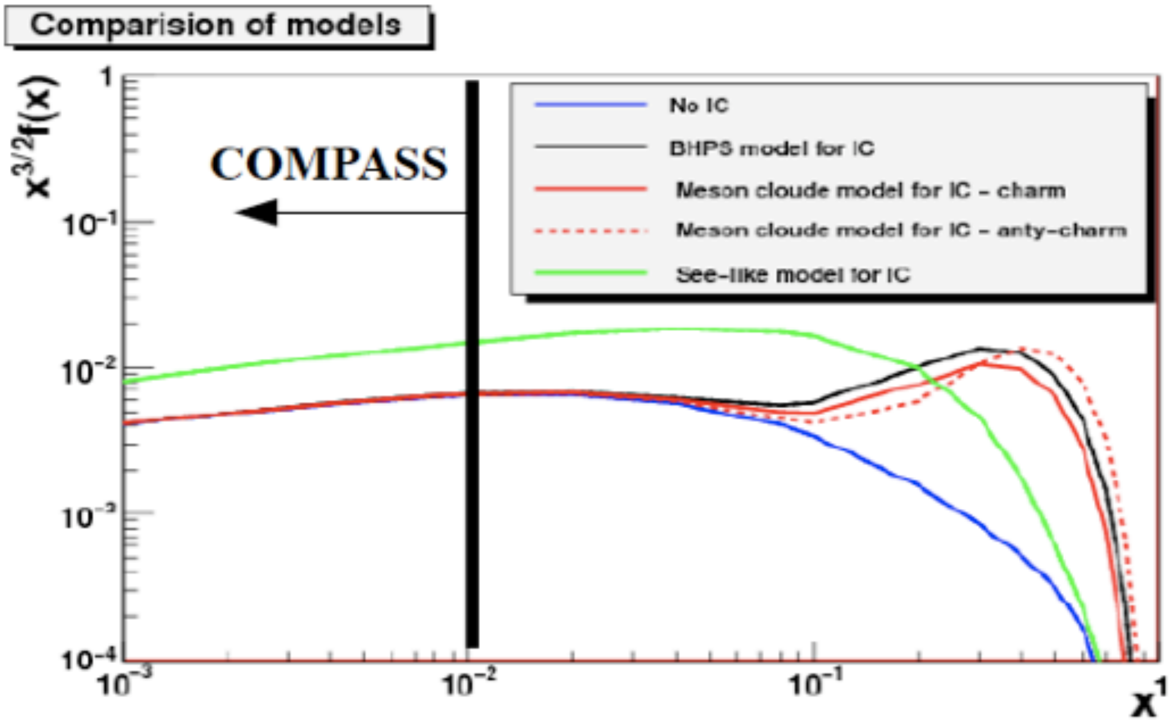
virtual photon energy fraction carried by D^0 meson

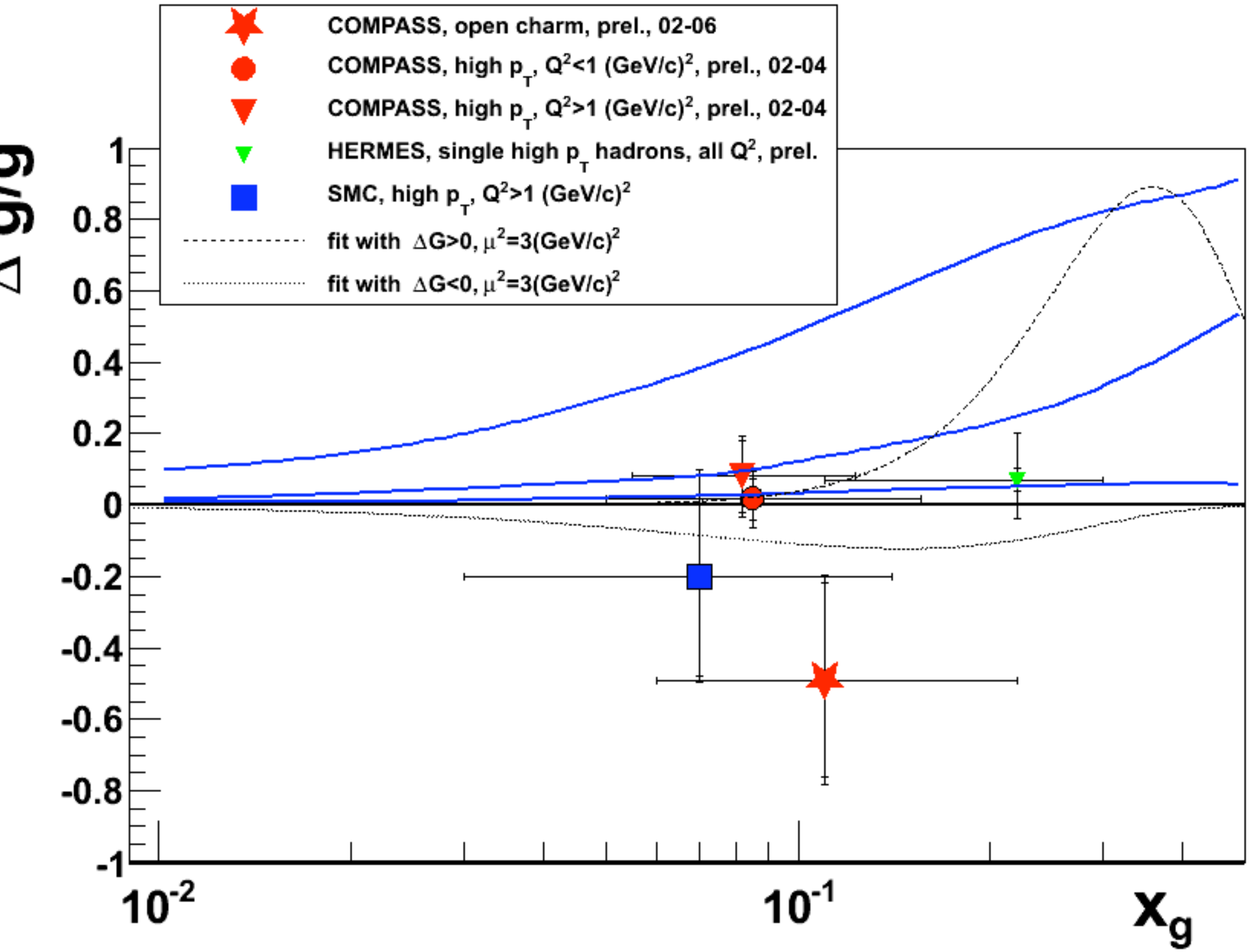


Ref. Hep-ph/0508126 and hep-ph/9508403
Phys. Lett. B93 (1980) 451
Data from EMC:Nucl.Phys.B213, 31(1983)

Intrinsic charm predictions: CTEQ6.5c

- **In the COMPASS kinematic domain:**
  - **No intrinsic charm contamination is predicted by the theory driven results**
  - **Only the more phenomenological *"See-like"* scenario should be taken into account *(under study)***





GRSV, ΔG

max, 2.5

std, 0.6

min, 0.2

Method for ΔG/G and polarised A_B extraction

- **The number of events comes from asymmetries in the following way:**

$$N_{u,d} = \boxed{a\,\phi\,n}(S+B)\left(1 + P_T P_\mu f\left(a_{LL}\frac{S}{S+B}\frac{\Delta G}{G} + a_{LL}^{B}\frac{B}{S+B}A_B\right)\right)$$

$a =$ acceptance, $\phi =$ muon flux, $n =$ number of target nucleons

- **We have 4 cell configurations** *(2 cells oppositely polarised + field reversal for acceptance normalization)*:
  - Weight the 4 $N_{u,d}$ equations by ω_s and by $\omega_B = P_\mu\, f \cdot D(y)\;(B/S+B)$

$$<\sum_{k=1}^{N_{cell}} \omega_i^k> = \hat{a}_{\boxed{cell},i}\left(1 + (<\beta_{cell,S}>\omega_i)\boxed{A_S} + (<\beta_{cell,B}>\omega_i)A_B\right) = f_{cell,i}$$

(cell = u , d , u' , d') **(ΔG/G)** **(i = S , B)**

$$\hat{a} = a\,\phi\,n\,\sigma = a\,\phi\,n(\sigma_{PGF} + \sigma_B) = a\,\phi\,n(S+B)$$

$$\beta_S = P_B P_T f\, a_{LL}\frac{S}{S+B} \qquad \beta_S = P_B P_T f\, D\frac{B}{S+B}$$

8 eq. with 10 unknowns

How to solve equations for simultaneous $\Delta G/G$ and A_B extraction?

- Possible acceptance changes with time are the same for both cells *(also the muon flux is the same for both cells):*

  $10 \Rightarrow$ 8 unknowns: 6 $\hat{a}$, A_S and A_B $\longrightarrow$ $\boxed{\dfrac{\hat{a}_{u,S}\hat{a}_{d',S}}{\hat{a}_{u',S}\hat{a}_{d,S}}=1 \quad , \quad \dfrac{\hat{a}_{u,B}\hat{a}_{d',B}}{\hat{a}_{u',B}\hat{a}_{d,B}}=1}$

- **Signal and background events are affected in same way before and after a field reversal:**

  $8 \Rightarrow$ 7 unknowns: 5 $\hat{a}$, A_S and A_B $\longrightarrow$ $\boxed{\dfrac{\hat{a}_{u,S}}{\hat{a}_{u,B}}=\dfrac{\hat{a}_{u',S}}{\hat{a}_{u',B}} \quad , \quad \dfrac{\hat{a}_{d,S}}{\hat{a}_{d,B}}=\dfrac{\hat{a}_{d',S}}{\hat{a}_{d',B}}}$

- **Unknowns are obtained by a χ^2 minimization:**

$$\boxed{\chi^2=(\vec{N}-\vec{f})^T \mathrm{Cov}^{-1}(\vec{N}-\vec{f})}$$

Validation of parameterization *(2006 example)*